Construction and Performance of a Portable Resistance Board Weir for Counting Migrating Adult Salmon in Rivers

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September 1994

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The correct citation for this report is:

Tobin, J. H. 1994. Construction and performance of a portable resistance board weir for counting migrating adult salmon in rivers. U. S. Fish and Wildlife Service, Kenai Fishery Resource Office, Alaska Fisheries Technical Report Number 22, Kenai, Alaska.

Abstract

Resistance board weirs provide an alternative method to conventional fish counting weirs and other escapement monitoring techniques. Using existing resistance board weirs as models, the basic design was adapted to meet portability and stream flow requirements associated with two remote rivers in western Alaska. Weir components were prefabricated from lightweight, durable materials and transported to each site by boat and helicopter.

The weir consists of a connected array of 6.1-m x 1.2-m panels with polyvinyl chloride pickets. The upstream end of each panel is hinged to a steel rail that is anchored to the stream bottom. The downstream end of each panel is lifted above the water surface by a 0.6-m x 1.2-m resistance board that planes upward in flowing water. Inclination of pickets is variable with fluctuating water levels and debris loading. Portions of the weir will sink beneath the water surface if loading on the panels overpowers lift created by the resistance boards.

The weirs were resistant to washout and virtually self cleaning during debris laden high water events. This design remained functional during discharges exceeding 1.6 m^3/s per linear meter of weir and withstood debris loads of trees, sod, dead fish, and ice floes.

Two weirs, totaling 140 m, were fabricated in about 920 man hours. Cost of materials, excluding shipping, was approximately $15,000 per weir in 1991. Four people installed each weir across 50-m wide sections of the Kwethluk and Tuluksak rivers in 5 days.

Five species of adult Pacific salmon *Oncorhynchus sp.* were enumerated and sampled for age, sex, and size composition. Only adult-sized Dolly Varden *Salvelinus malma*, round whitefish *Prosopium cylindraceum*, humpback whitefish *Coregonus pidschian*, broad whitefish *C. nasus*, Arctic grayling *Thymallus arcticus*, and northern pike *Esox lucius* were counted and sampled because smaller sized fish escaped between pickets.

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Introduction

In 1991, a multi-year investigation was undertaken to improve salmon management in the lower Kuskokwim River drainage in western Alaska (Harper 1994a, 1994b). Two major tributaries, the Kwethluk and Tuluksak rivers, were selected as indicators of migratory timing and run strength of five species of Pacific salmon. A reliable method of enumerating adult chinook *Oncorhynchus tshawytscha*, chum *O. keta*, coho *O. kisutch*, pink *O. gorbuscha*, and sockeye *O. nerka* salmon by species was required for these rivers. Biological sampling to determine age, sex, and size composition was also necessary. Additionally, baseline information would be collected from Dolly Varden *Salvelinus malma*, round whitefish *Prosopium cylindraceum*, humpback whitefish *Coregonus pidschian*, broad whitefish *C. nasus*, Arctic grayling *Thymallus arcticus*, and northern pike *Esox lucius* that were incidentally counted or captured.

Cousens et al. (1982) reviews many techniques that are available for biological sampling and monitoring escapement of adult salmon; however, only weirs are capable of producing immediate and reliable results that were requisite for these projects.

A portable weir design was required, because the Kwethluk and Tuluksak rivers are remote and accessible only by boat or helicopter. These rivers are prone to large fluctuations in discharge and often carry a large amount of debris, thus requiring a weir resistant to washout. Complete removal of the weirs at the end of each season was also necessary due to severe winter ice conditions, so ease of installation and removal was also desirable.

A variety of portable weirs made of wood, metal, plastic, wire, or netting are used for escapement monitoring (Blair 1956; Clay 1961; Anderson and McDonald 1978; Moores and Ash 1984; Noltie 1987; Hill and Matter 1991). Portable rigid weirs made primarily of wood or metal and similar in design to weirs described by Clay (1961) and Anderson and McDonald (1978) are typically used in Alaskan rivers. They are stronger and easier to maintain than weirs made of materials such as wire or netting (Kristofferson et al. 1986), but require frequent cleaning when rising water brings a large amount of debris downstream.

Vulnerability to washout limits the effective use of portable rigid weirs to streams that carry relatively small debris loads and experience infrequent high water events. These weirs are often lost downstream to high water when they become congested with debris and weakened by the effects of water velocity (Clay 1961; Anderson and McDonald 1978). Washout is sometimes avoided by removing the pickets and allowing debris to wash downstream (Anderson and McDonald 1978; Hill and Matter 1991), but this can result in large numbers of fish passing upstream undetected.

Resistance board weirs are a relatively new alternative to other weirs and are capable of consistently producing reliable information in streams that experience debris laden high water periods. Although not impervious to washout, this type of weir is more resilient than a rigid weir. A resistance board weir will temporarily submerge when pressure created by water velocity and debris loading reaches a point that might wash a rigid weir downstream.

Unfortunately, resistance board weirs are among the least portable of all weirs. Although recent adaptations (Bartlett 1988; Booth 1993) have expanded their use to increasingly remote rivers, the cost of transporting these weirs remained restrictive because of their weight and bulk. Portability was further limited by the length of time required for installation and removal. The abutments and foundations of existing designs were better suited as long-term or permanent structures.

Resistance board weirs continue to gain popularity as a management and research tool, but relevant design and installation information is virtually unavailable. This paper will familiarize the reader with a portable resistance board weir designed for use on remote rivers. Information is provided on construction, installation, and design factors affecting performance. Operational performance is also evaluated and suggestions for modification are discussed.

Study Area

The Kwethluk and Tuluksak rivers are major tributaries to the lower Kuskokwim River in western Alaska. Originating in the Kilbuck Mountain Range, both tributaries cut through tundra and support narrow riparian zones of willow, spruce, cottonwood, and birch (Alt 1977). Upper reaches of these rivers are clear, fast flowing, and include the majority of spawning habitat for salmon. The lower 50 km of the streams are characterized by tannin-stained, turbid waters meandering slowly through a deep mud-lined channel. Precipitation averages approximately 50 cm annually, with the majority falling between June and October. Seasonal high water periods are generated by snowmelt runoff from late May to early June and rainfall in September.

Kwethluk River

The 222 km Kwethluk River main stem encompasses a watershed area of 3,367 km^2. The weir site (60°29'N, 160°05'W) is located 50 km SE of Bethel, Alaska, approximately 80 river km upstream from the mouth. The river in this area is characterized by swift runs and riffles with a bed composition of mostly medium sized gravel. Braided channels are present below the weir site but are most common upstream. Bank erosion 0.5 km upstream of the site results in turbid water for most of the summer. The installation site is located in a straight stretch of river upstream of a gravel island where the channel becomes shallow and widens from approximately 30 m to 51 m.

Tuluksak River

The 138 km Tuluksak River main stem encompasses a watershed area of 2,098 km^2. The weir site (60°59'N, 160°33'W) is located 70 km NE of Bethel, approximately 76 river km upstream from the mouth. The river near the study site follows a meandering course and flows slower than the Kwethluk River. The channel is characterized by glides and riffles flowing over a stream bed of mostly fine and medium sized gravel. Water is typically clear except during high discharge periods. The installation site is located in a straight stretch of river where the channel becomes shallow and widens from approximately 25 m to 48 m.

Concept

A resistance board weir consists primarily of an array of rectangular panels (Figure 1). The panels are made of evenly spaced tubular pickets aligned parallel to the direction of flow. The upstream end of each panel is hinged to a rail that is anchored to the stream bottom. The downstream portion is lifted above the water surface by a resistance board that planes upward in flowing water. When the panels and other components are installed, the resulting barrier inhibits adult fish migration, yet allows water to pass. One or more openings in the weir, typically formed by a passing chute, direct fish into a live trap or allow them to be counted as they migrate upstream.

It is critical to consider flow characteristics of a stream when designing a resistance board weir. Weir performance is both dependent on and limited by the force of flowing water. Flowing water provides lift to the resistance board and also exerts counteracting downward pressure on the upstream face of the panels. Downward pressure on the panels is increased when head upstream of the weir builds due to the constriction of flow between the pickets. If the lift created by the resistance boards is overpowered by downward pressure on the panels, portions of the weir will submerge.

Maximum weir performance can be achieved by tailoring resistance board size and position, panel length, picket spacing, and picket diameter to the flow characteristics of the target stream. Resistance board size and position will determine the amount of lift applied to the panels. Panel length, picket spacing, and picket diameter will determine the amount of downward pressure applied on the panels.

The resistance board delivers lift to the downstream portion of each weir panel by providing a planing (resisting) surface that reacts to the hydrodynamic force of flowing water (Figure 2). A larger resistance board will generate more lift, because the added

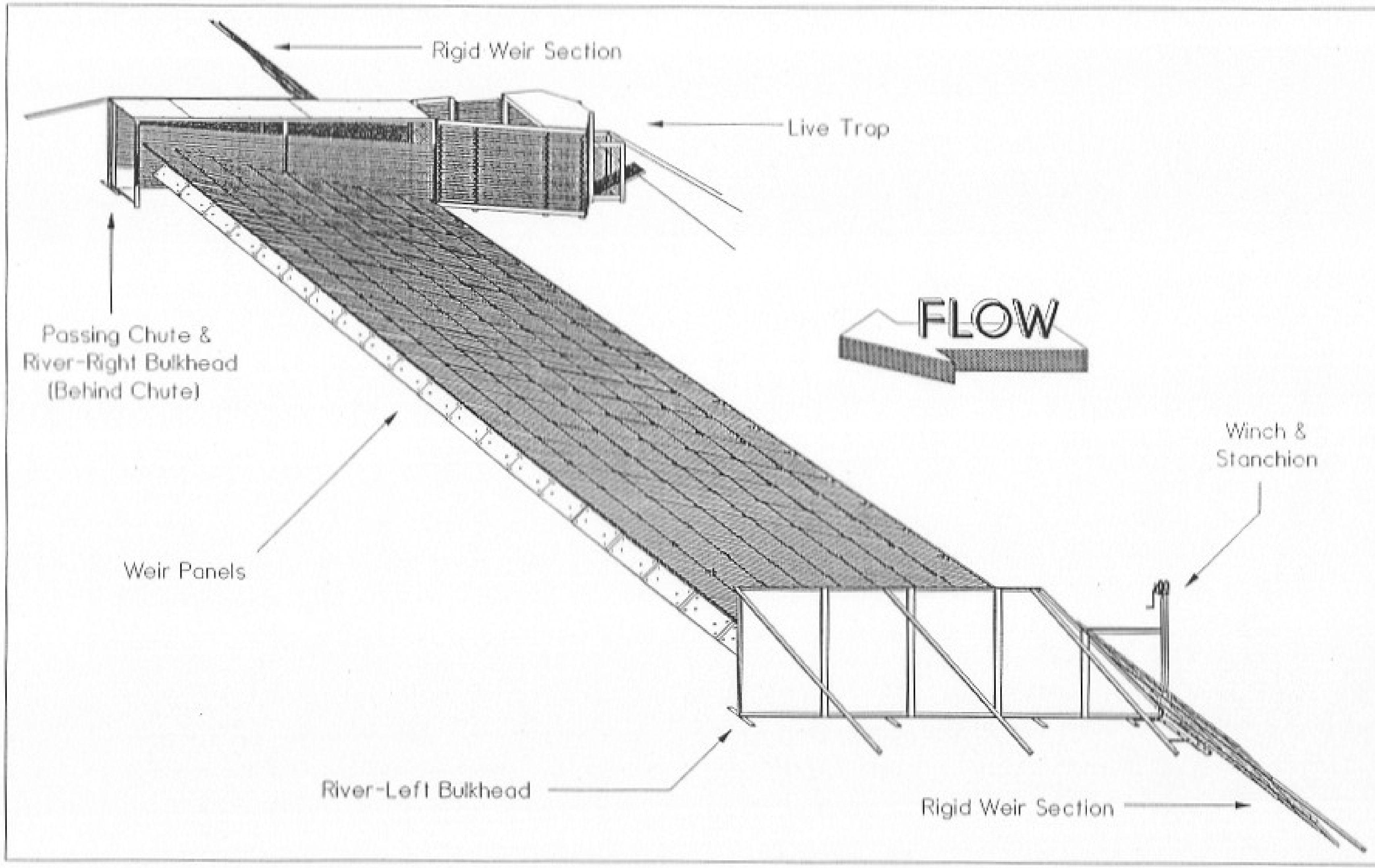

FIGURE 1.—An assembled resistance board weir spanning 33 m (boat passage panels not shown).

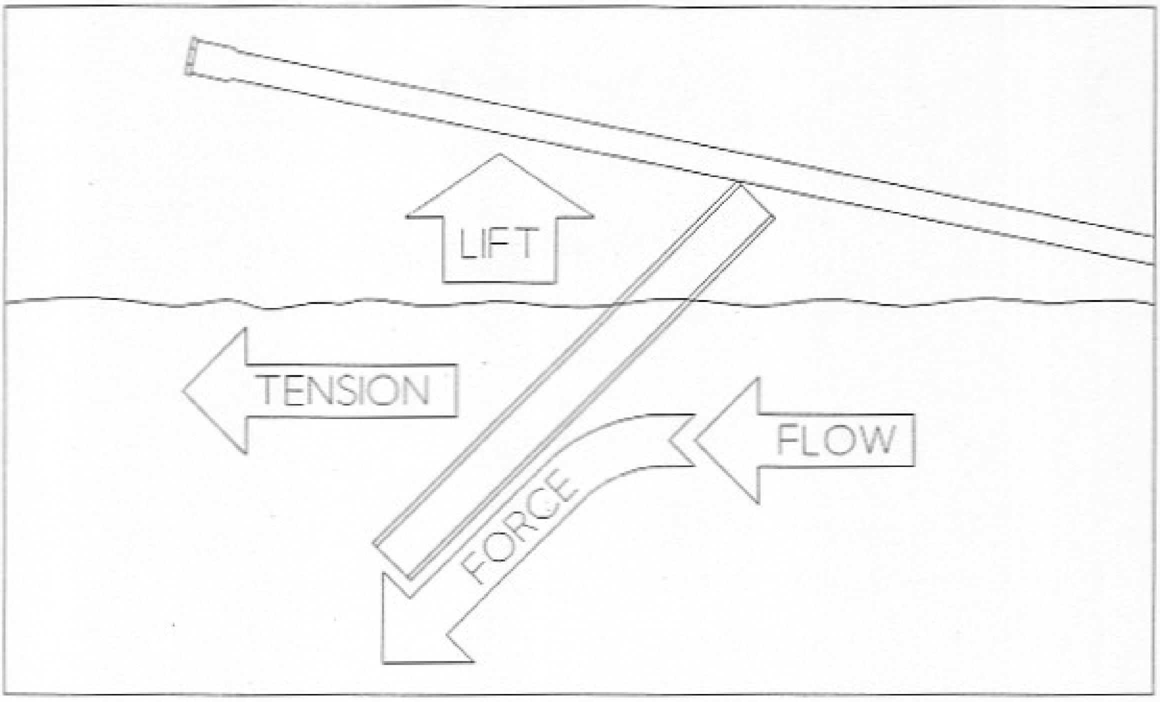

Figure 2.—Lift and tension are generated as the resistance board reacts to hydrodynamic force exerted by flow.

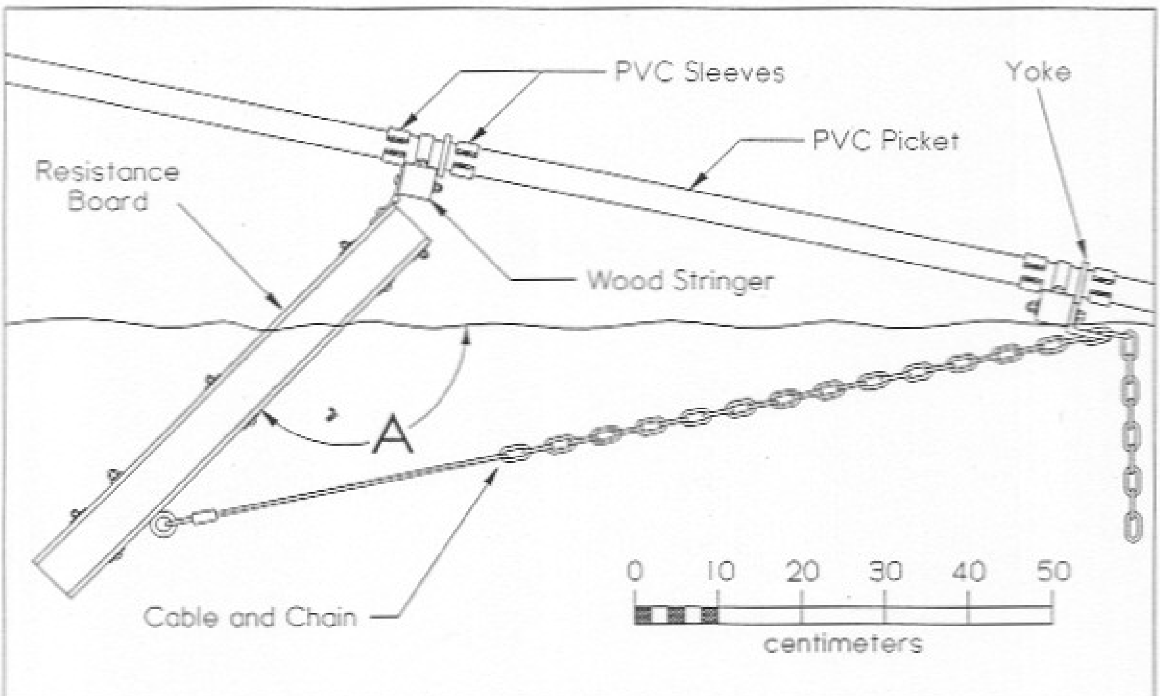

Figure 3.—Lateral view illustrating the downstream portion of a weir panel. "A" (angle of the resistance board relative to horizontal) is typically 130° to 140°.

surface area reacts to the increased amount of force contained in a larger volume of water. To achieve a maximum amount of lift, the resistance board should be set at an angle that permits efficient upward planing. This angle is typically 130° to 140° relative to horizontal (Figure 3).

In addition to lift, tension is generated by the resistance board (Figure 2). Tension is created when flow exerts a downstream pushing force on the board. Larger resistance boards or boards set at steep planing angles will create more tension. The amount of tension generated dictates how securely the weir panels must be anchored to the stream bottom.

Weir performance is also affected by panel length. As panel length increases, inclination of pickets decreases. This provides more submerged open area for water to pass between pickets, thus reducing the differential in head upstream and downstream of the weir (Clay 1961). Reduced head differential results in decreased water pressure on the upstream face of the weir, and less force is required to lift the panels above the water surface.

Picket spacing and diameter affect head differential similarly to panel length. Head differential is reduced when picket spacing is increased or diameter is decreased, because more open area is available for water to pass through the weir (Clay 1961).

Design

The first resistance board weir in Alaska was installed at the Russell Creek Hatchery in 1986 (Holmes 1992). This Japanese manufactured weir (Daishin Kogyo Co., Ltd. distributed by Mitsubishi International Corp., Seattle, Wa.) featured elliptic polyvinyl chloride (PVC) pickets attached to wood stringers with custom fit stainless steel bands. Steel, rock, and poured concrete were used for abutments and substrate foundation. Extensive stream bed preparation and the need for specialized construction techniques made this design expensive and impractical for use on the majority of Alaskan rivers.

Alaska Department of Fish and Game (Department) later adapted the Russell Creek design for use on other rivers (Bartlett 1988; Booth 1993). Notable modifications included changes to the substrate foundation, the addition of a boat passage area, and use of relatively inexpensive, locally available materials for construction. Railroad rail was substituted for the concrete substrate foundation to simplify installation. Consequently, installation cost was reduced. Modified panels with down-turned pickets were designed to easily pass boats over the weir. Relatively inexpensive PVC conduit and conduit hangers were used in place of the elliptic pickets and stainless steel picket-to-stringer attachment system used by the Japanese.

Adaptations by the Department improved the practicality of using resistance board weirs on Alaskan rivers, but further modification was required for use on the Kwethluk and Tuluksak River projects. Portability was limited because the substrate rail was too heavy, the abutments required stream bank excavation, and other components were bulky or required custom fitting on site. Connections between components were sometimes difficult and time consuming when done underwater.

Modifications to existing designs resulted in a relatively lightweight weir (Appendix A) that was easier to install. Reducing the weight of the substrate rail from 165 kg to

40 kg per 3 m was foremost in improving portability. Substituting lightweight, freestanding bulkheads for heavy abutments further improved portability and allowed quick installation without stream bank excavation. Installation of components was also simplified by using hooks for many of the underwater connections. Long panels with wide picket spacing and large resistance boards provided optimal performance during high flows.

Measurements given in the following paragraphs are outside dimensions unless otherwise noted. River-right and river-left refer to the right and left side of the river when facing downstream. Critical trade sizes and dimensions are parenthesized in English units to eliminate rounding errors during conversion from metric units.

Substrate Rail

The substrate rail anchors and aligns the 10-mm ($^3/_8$ in) cable upon which panels are attached (Figure 4). It must be rigid enough to remain straight without the aid of excessive fastening to the stream bottom, yet be light enough for transport to remote sites. The rail is constructed from 3-m (10 ft) lengths of 7.6 cm (3 in) x 7.6 cm x 6-mm ($^1/_4$ in) structural steel angle. Three 91-cm long steel legs are bolted to each length of angle to provide stability. Apron hooks are welded to the angle at 50-cm intervals to provide attachment points for the apron. Cable guides are welded to the face of the rail at 60-cm intervals to provide support for the 10-mm cable.

Apron

The apron in this design functions as a barrier to fish passage beneath the rail. The apron is fabricated by threading lengths of 10-mm ($^3/_8$ in) steel rod into the upstream and downstream margins of 90-cm (36 in) wide, 5-cm (2 in) mesh chain link fence (Figure 5). The steel rod is necessary to keep the upstream and downstream margins of the apron flat against the rail and the stream bottom.

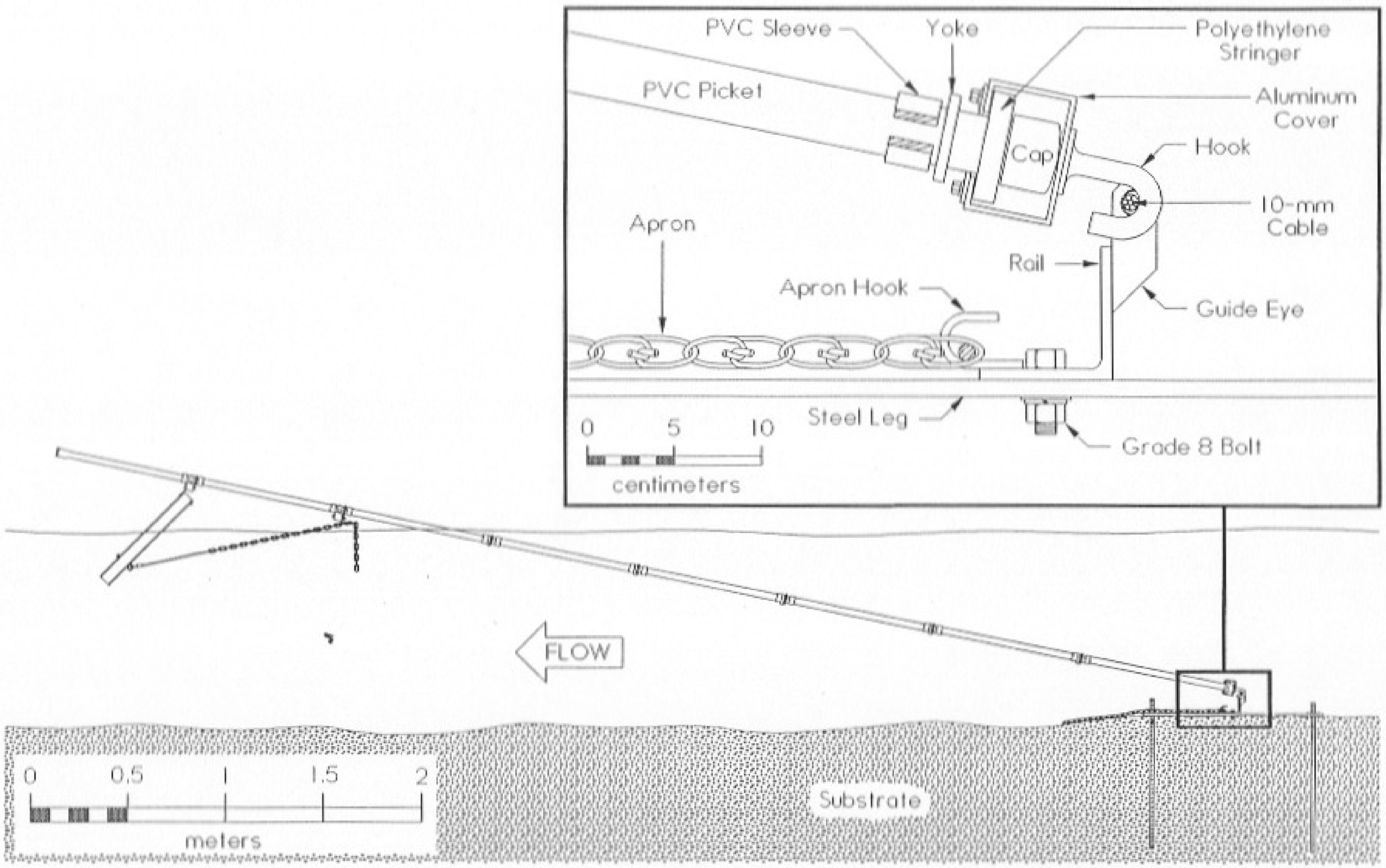

FIGURE 4.—Lateral view of an installed weir panel. Inset detail shows apron and panel attachment to the substrate rail and 10-mm cable.

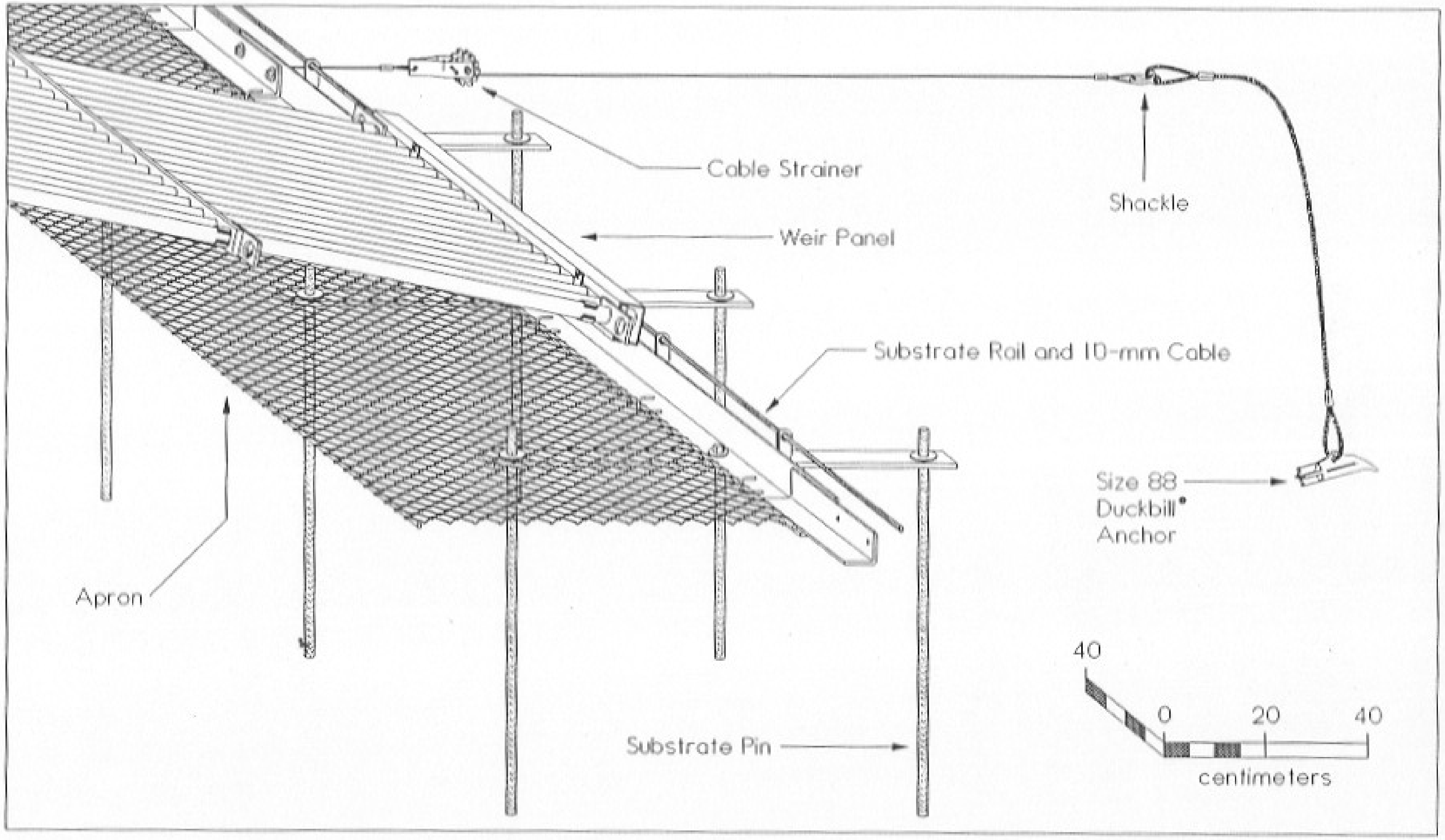

FIGURE 5.—The substrate rail and 10-mm cable with the weir panel and apron attached.

Bulkheads

Bulkheads (Figures 1, 6, and 7) provide a terminus for the weir panel assembly similar to abutments described by Clay (1961). Unlike heavy abutments that are built into or against the stream bank, bulkheads are thin vertical walls positioned away from the stream bank. As the panel adjacent to the bulkhead rises and falls with fluctuating water levels, a consistent gap is maintained between the two. This interface provides a fish-tight terminus for the weir panels at a variety of water levels.

The bulkheads are equal in length to the weir panels and tall enough to remain above water during high water events. They consist of a plywood covered aluminum frame measuring 6.1-m long and 1.8-m tall. The upstream end is sloped at a 45° angle to accommodate a span of rigid weir extending to the bank. Three flat steel legs bolted to the base of each bulkhead provide additional stability and accept substrate pins to prevent lateral movement. When installed, three 4.6-m long steel angle struts extend from the top of each bulkhead to the stream bank to provide vertical stability.

Rigid Weir Section

Fish passage between each bulkhead and stream bank is prevented by a section of rigid weir (Figures 1, 6, and 7). The rigid weir is made of two horizontally positioned aluminum angle stringers with holes spaced 6.0 cm center to center. The stringers are attached to the bulkhead and the stream bank, and 2.7-cm ($1^1/_{16}$ in) diameter x 2-m long pickets are inserted through the holes to form a fish-tight barrier.

Bulkhead Adapter

An adapter is used to connect the river-right bulkhead to the substrate rail (Figure 7). The bulkhead adapter is a "T" shaped steel plate with a clamping device that fits around the rail. Two threaded studs protrude from the base to accept the bulkhead. Using the adapter, the bulkhead can be placed practically anywhere along the rail.

Winch Stanchion

The winch stanchion functions as a winch pedestal and rail adapter for the river-left bulkhead (Figure 6). It consists of a "T" shaped steel base similar to the bulkhead adapter. A 1.8-m steel channel post is welded to the base, and the stanchion is bolted to the substrate rail. A steel angle strut is bolted 1.2 m from the base of the post and connected horizontally to the bulkhead to stabilize the stanchion.

A 1,590 kg (3500 lb) winch is mounted on top of the post during weir installation. The 10-mm cable, which is anchored at the opposite end of the weir, is routed through

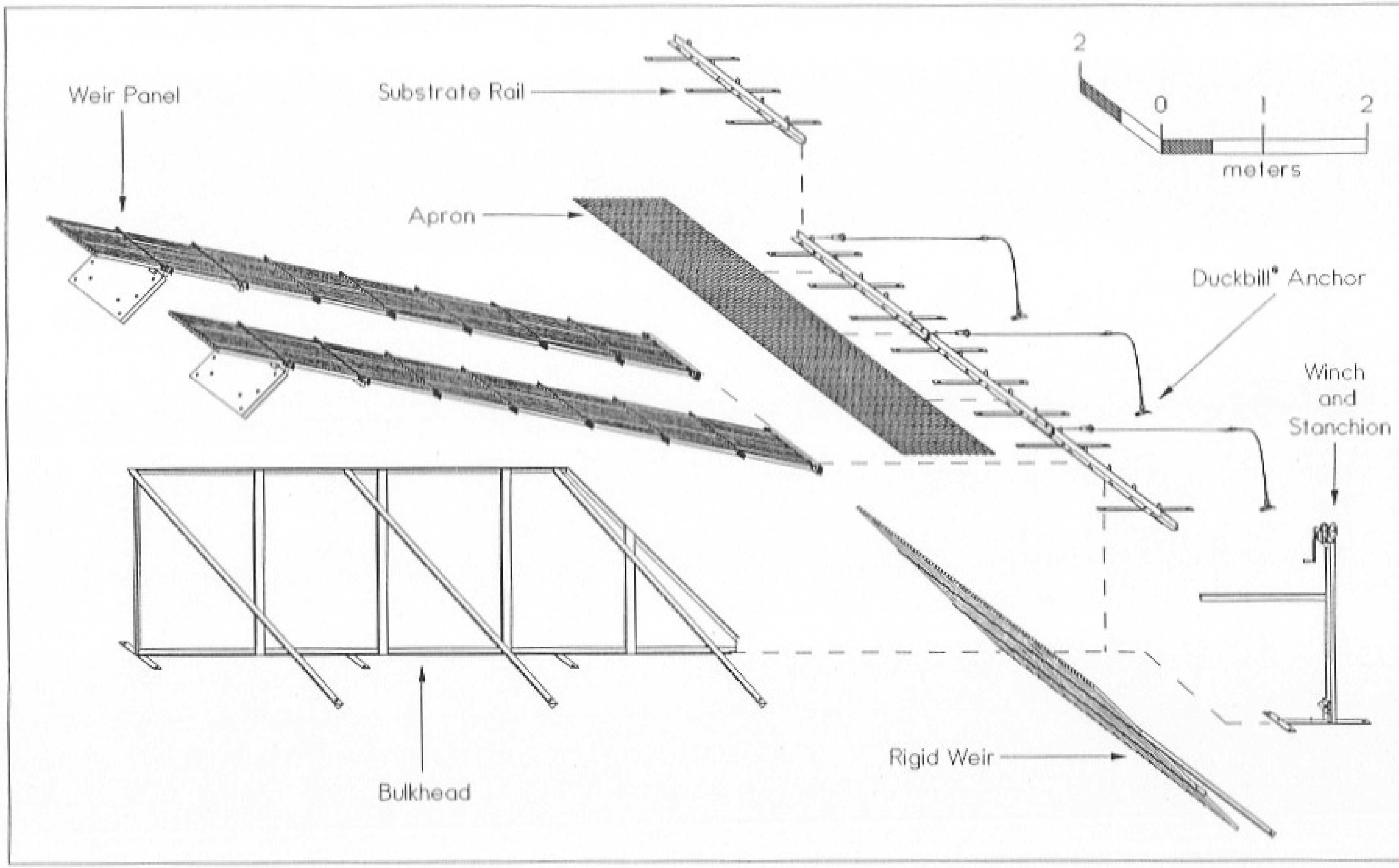

FIGURE 6.—Exploded view showing the major components at the river-left section of weir.

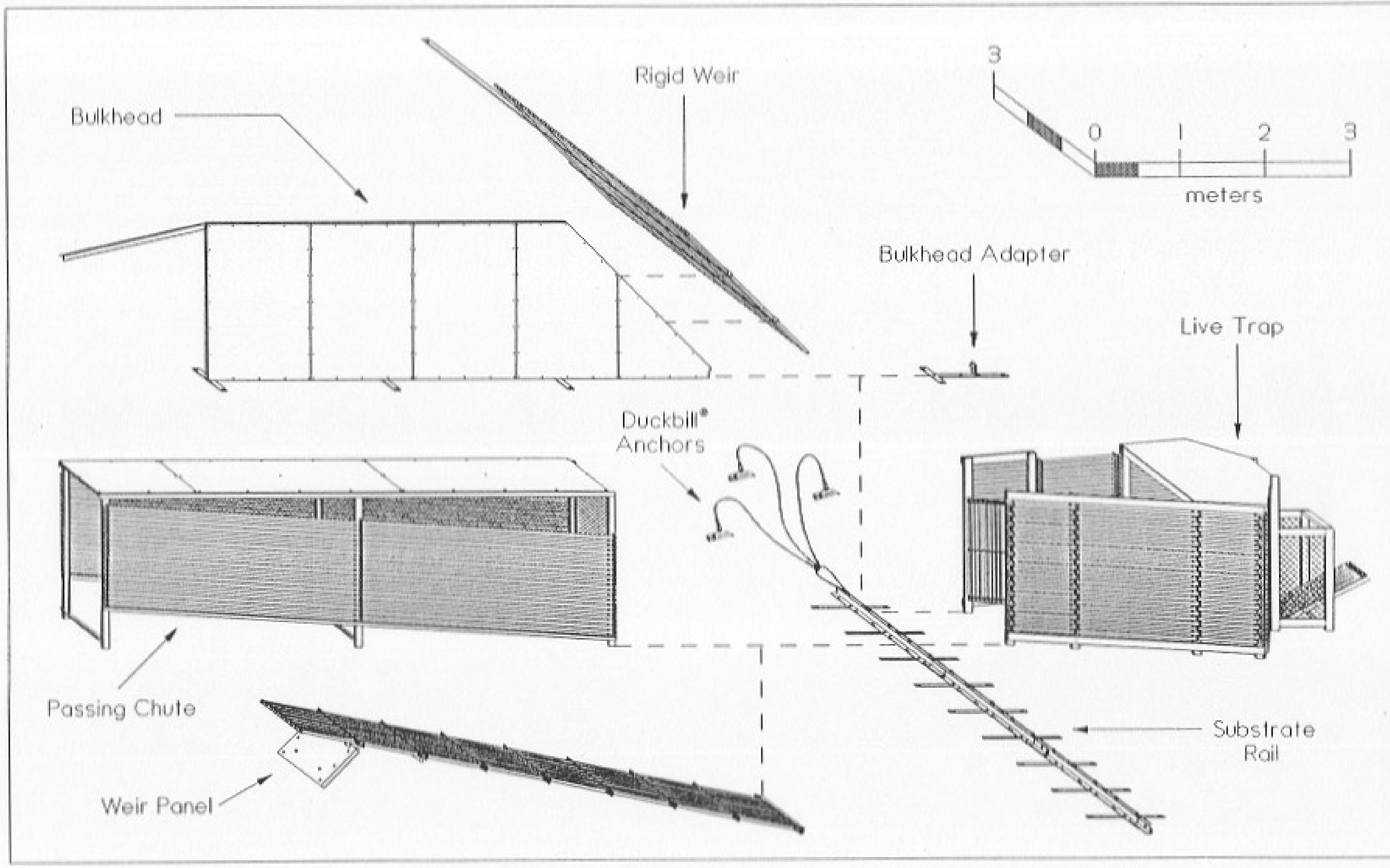

FIGURE 7.—Exploded view showing the major components at the river-right section of weir. Duckbill® anchors secure the 10-mm cable to the stream bed.

guide eyes on the rail, around a sheave mounted near the base of the stanchion, and up to the winch. The winch provides tension to the cable.

Weir Panels

The weir panels create a fence-like barrier across the stream when connected together. Each panel is constructed using eighteen 6.1-m (20 ft) lengths of 2.5-cm (1 in) inside-diameter schedule 40 PVC electrical conduit as picket material. Electrical conduit was chosen rather than PVC water pipe, because it resists breakdown caused by exposure to ultraviolet light.

The pickets are secured at the upstream end of the panel by inserting them through holes in a 1.2-m (4 ft) long polyethylene stringer, then gluing caps over the protruding ends (Figure 4). A cover, fabricated from 7.6-cm (3 in) x 5.1-cm (2 in) x 3-mm ($^1/_8$ in) rectangular aluminum tubing, is slipped over the plastic stringer and the caps to form a base stringer. The shafts of two hooks are inserted through the base stringer to lock the system together and provide a method for attaching the panels to the 10-mm cable. A plug glued into the downstream end of each picket (Figure 8) provides a watertight seal making each picket buoyant.

Center to center picket spacing of 6.8 cm is maintained throughout the length of the panel by five polyethylene stringers and a pair of wood stringers with conduit hangers (Figure 8). The stringers are spaced at 76-cm intervals and slippage is prevented by gluing PVC sleeves onto the pickets.

Each resistance board (Figure 3) measures 0.6-m (2 ft) high and 1.2-m (4 ft) wide. They are constructed by laminating and bolting a 3.8-cm (1$^1/_2$ in) thick sheet of waterproof styrofoam between two sheets of 6-mm ($^1/_4$ in) thick plywood. The plywood is protected against water damage with a double coat of marine enamel paint. During weir panel fabrication, the resistance board is hinged to the downstream wood stringer. When the panels are installed, resistance angle is maintained by a cable and chain combination leading from the resistance board to a chain latch on the upstream wood stringer.

Plastic yokes are used to couple the panels together during installation (Figure 8). They are made by drilling two 3.7-cm (1$^7/_{16}$ in) holes through 14.0-cm x 5.1-cm polyethylene rectangles. One hole of each yoke is fitted around the outermost picket on both sides of the panel immediately upstream of each stringer. Panels are coupled together by threading a connector picket through the second hole of each yoke.

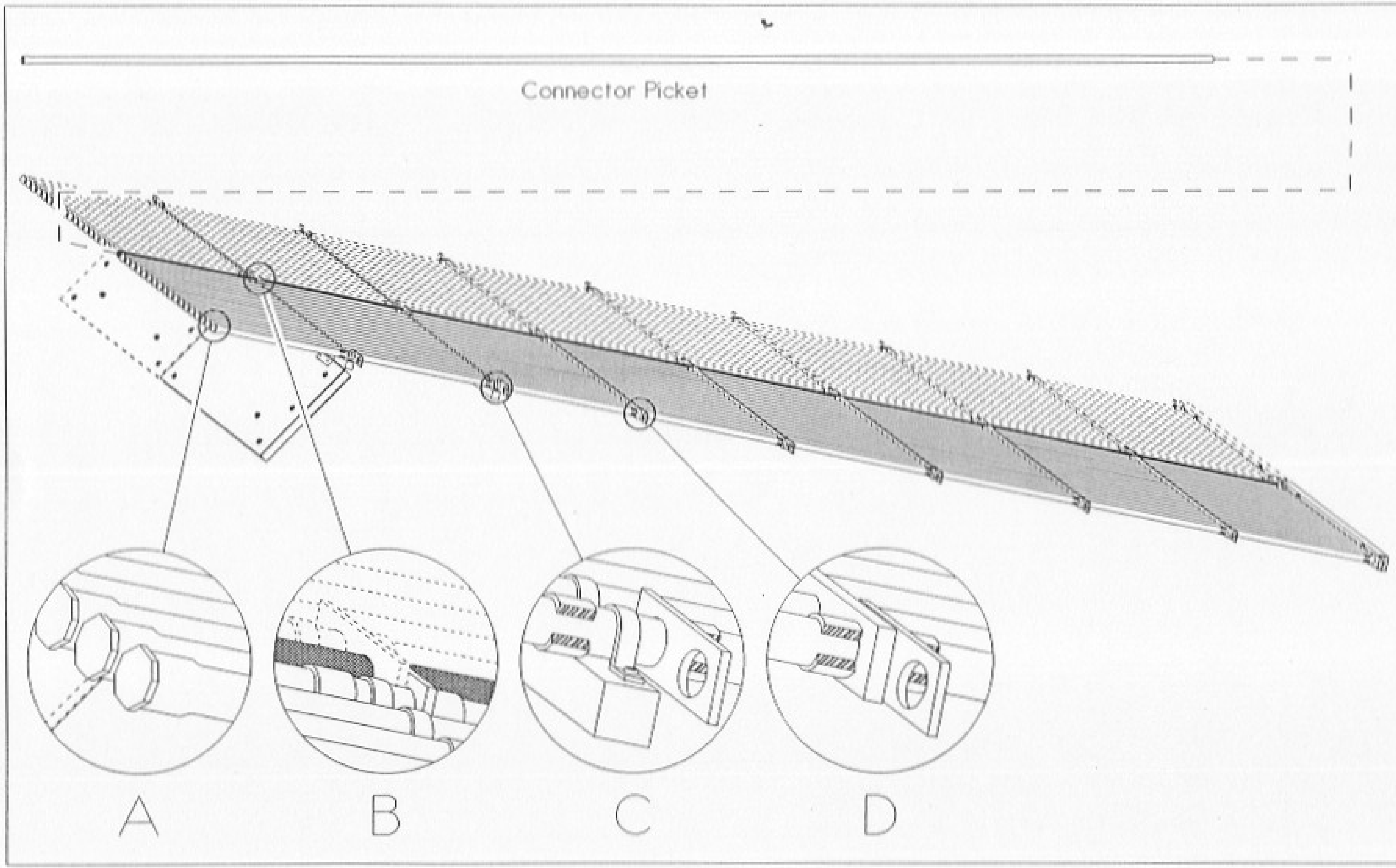

FIGURE 8.—Two weir panels coupled by a connector picket: (A) Water-tight plugs; (B) Connector picket [shaded] threaded through the yokes of two panels; (C) PVC sleeves, wood stringer, conduit hangers, and yoke; and (D) PVC sleeves, polyethylene stringer, and yoke.

Fish Passing Chute

The fish passing chute allows fish to swim through an opening in the weir and into a live trap (Figures 1, 7 and 9). Chute components consist of three aluminum frames, four aluminum stringers, two side panels, a gate, and a plywood deck.

The frames are constructed to a height of 1.8 m and a width of 1.2 m using aluminum channel as vertical members and aluminum angle as horizontal members. Aluminum angle stringers connect the frames together at 3-m intervals to form a 6-m long chute. A plywood deck is bolted on top of the framework to provide a walking surface and additional strength. Two turnbuckle jaws, bolted to the base of the upstream frame, attach the chute onto the 10-mm cable when it is installed.

Two side panels are constructed of PVC conduit pickets and polyethylene stringers. They cover the two long sides of the chute providing an interface much like that between weir panel and bulkhead. Unlike a bulkhead, the side panels do not extend to the stream bottom. The downstream and upstream end of each panel is installed 50 cm and 8 cm above the stream bottom respectively. This is essential to permit unobstructed movement of fish from under the weir panels into the chute.

The gate consists of PVC pickets in a 1.70-m x 1.19-m aluminum angle frame. The gate slides into the vertical channels of the frame at the upstream end of the chute. It can be closed to block the entrance of the live trap during sampling or when fish are not being passed.

Live Trap

A live trap is necessary for biological sampling of fish. The trap (Figures 7 and 9) measures 1.8-m high, approximately 3.5-m long, and width varies from 1.2 m to 2.4 m. Total inside area is approximately 5.4 m^2. The walls are constructed of wood stud framing and PVC pickets. A sandbag floor is added after trap installation.

Fish enter the trap through a "V" shaped passageway which makes it difficult for them to return downstream. The passageway is formed by two aluminum framed PVC picket doors that can be opened and secured to the side of the trap for unobstructed access to fish while netting.

Upon entering the trap, fish are either sampled and released into a sanctuary area above the weir or counted through a gate located at the upstream end. The gate, made of PVC pickets framed by aluminum angle, is hinged at the base, allowing it to be lowered to a depth suitable for identifying fish as they pass upstream. Perforated walls on both sides of the gate prevent fish from escaping to either side before reaching the upper edge of the gate. Fish counting is done from a plywood deck on top of the trap.

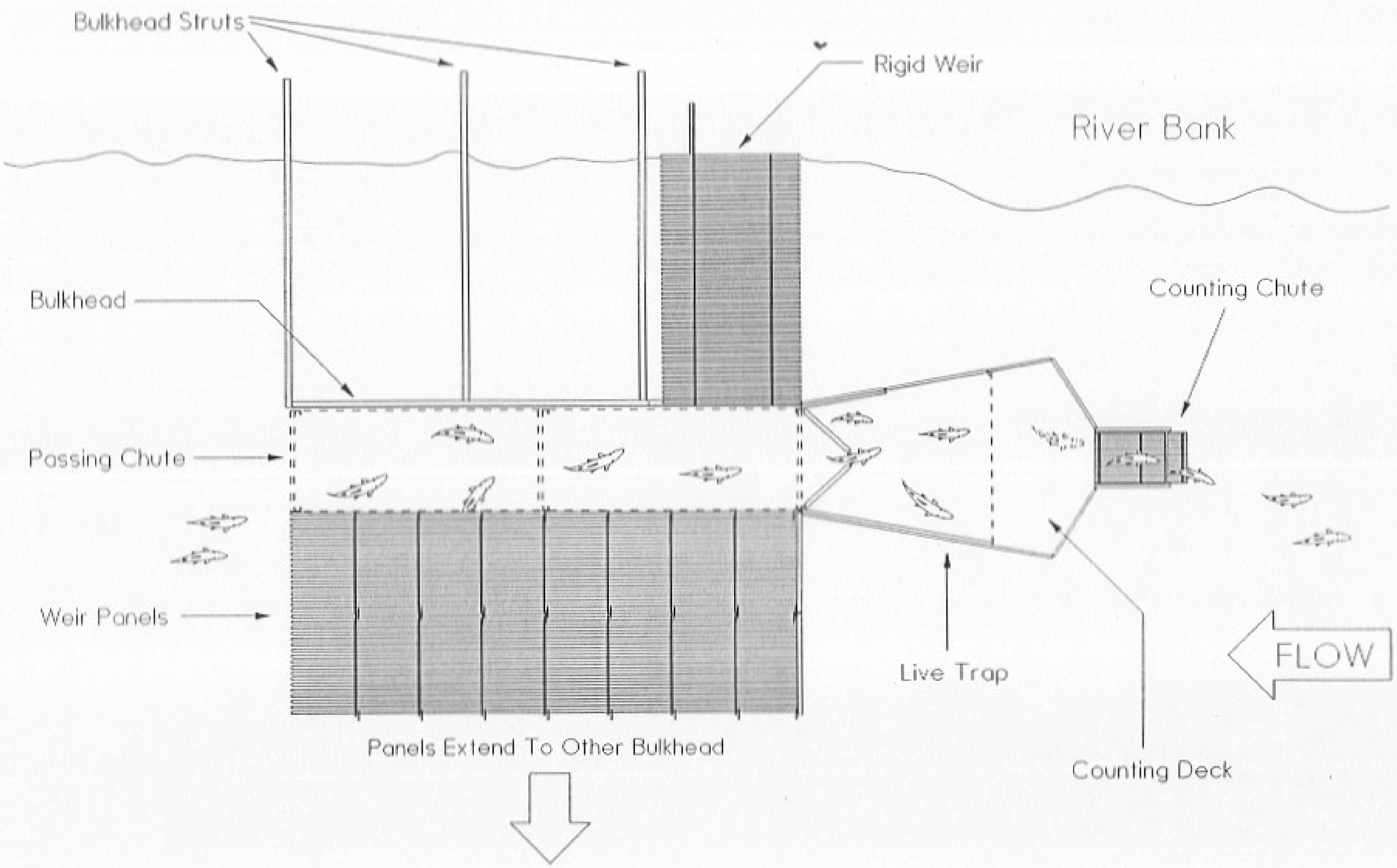

FIGURE 9.—Overhead view illustrating the river-right section of weir and fish passage through the passing chute and live trap.

Site Selection

The hydrological and geological characteristics at the installation site strongly influence weir performance. Suitable resistance board weir sites are similar to sites described by Clay (1961) and are characterized by wide, shallow areas of stream with a stable substrate foundation.

A resistance board weir site should also be located at a relatively straight section of stream. Laminar flow is important, especially if panels are attached to a cable with open hooks. If a portion of the current deviates from the general direction of flow, it can force the affected panels to become unhooked from the cable. However, a small amount of angular flow is tolerable. For example, during low water periods on the Kwethluk River, a portion of current near a gravel bar was deflected as much as 15° off course, yet all the panels remained hooked. Theoretically, an individual panel of this design could become unhooked if the current were to deviate more than 2° from a course perpendicular to the 10-mm cable. However, properly oriented panels connected to those affected countered the influence of the angled flow.

Water depths less than 1 m during normal flows and slow to moderate water velocity are preferred for this design. Generally, if the water is too deep and swift for a wading adult to stand during normal flow, the site is not suitable for a weir.

An ideal channel cross section will have a level stream bottom and uniform flow. This enhances the ability of the weir to function during high water events, because flow is more evenly distributed across the entire weir.

Near vertical stream banks are preferable to gently tapered banks, because steep banks are easily sealed against fish passage with the rigid weir sections. Banks should also be high enough to contain water during floods, because water flowing over the banks could erode a channel around the weir (Clay 1961). Extremely undercut banks or areas suspect to subterraneous channels should be avoided; sealing them against fish passage is often difficult or impossible. A change in flow patterns caused by the weir could also accelerate erosion in these areas.

A stream bottom of coarse gravel (> 3.2 cm) or small cobble (< 13.0 cm) is best for the size 88 and size 138 Duckbill® anchors used in this design. If an alternative method of anchoring is devised, a substrate composition of cobble or larger material would be less likely to erode than silt, sand, or gravel.

Fabrication & Installation

Two 70-m weirs were fabricated by two to four Service technicians and a welding contractor. Each weir required approximately 400 Service hours and 60 contractor hours for fabrication (Appendix A). The use of specialized jigs for boring holes, cutting materials, and assembling panels expedited the fabrication process and facilitated production of interchangeable parts. After transporting the components and necessary equipment to the sites, each weir was installed by four people in about five days.

Installation was begun by stretching a 3-mm ($^1/_8$ in) cable across the river where the substrate rail was to be placed. The cable was oriented 0.5 to 1.0 m above the surface of the water and adjusted perpendicular to the direction of flow. The cable served as a reference for maintaining alignment of substrate rail. The winch stanchion was bolted to the first section of substrate rail, and placed on the stream bottom near the river-left bank. The rail was then anchored to the stream bed plumb to the 3-mm cable.

Additional sections of rail were placed on the stream bed and bolted together. As each section was connected, a size 88 Duckbill® anchor was driven approximately 2 m upstream of the splice joint. A cable strainer, 3-mm cable, and shackle linked the Duckbill® anchor to the rail (Figure 5). The rail was adjusted plumb to the cable spanning the stream using the strainer. The rail was then staked to the stream bottom by driving a pin through the upstream end of each rail leg.

After all the rail was in place, a length of 10-mm cable was threaded through the cable guides and anchored to the substrate at the river right bank with three size 138 Duckbill® anchors (Figure 7). The cable was routed to the winch mounted on the stanchion and tightened. The bulkheads were then fastened to the rail and temporarily staked into place.

The apron was hooked onto the rail between the bulkheads, and pins were driven through the downstream end of each rail leg (Figure 5). The pins also aid in holding the apron against the stream bed.

After the substrate pins were driven, the panels were installed. The first panel was hooked onto the 10-mm cable adjacent to the river-left bulkhead, and a second panel was placed upside down on top of it. A connector picket threaded through the yokes on both panels hinged the two together (Figure 8). The second panel was then flipped over and hooked onto the cable. A hose clamp, installed around the connector picket and adjacent to the yokes, locked it into place. This process was repeated until a point 2 to 3 m from the river-right bulkhead was reached.

The passing chute was secured to the 10-mm cable in the open area between the panels and the bulkhead. The area near the bulkhead was best for fish passage, because strong flow, deep water, and stream bank cover was present. Deeper water downstream served as a holding area from which the fish could easily locate and enter the chute. However, the passing chute can be placed anywhere along the rail where adequate attraction flow and water depth are present.

After being secured to the 10-mm cable, the passing chute was fastened to the bulkhead. The remaining panel was installed, then the chute and bulkheads were plumbed and adjusted laterally allowing panels to move vertically without binding during fluctuating water levels. The live trap was attached to the upstream end of the chute and secured to the stream bottom with size 138 Duckbill® anchors.

A fish-tight interface was maintained between the terminal weir panels and the bulkhead or passing chute with panel retainers made of metal and plastic (Figure 10). Uniform spacing at this interface is maintained by the retainers as the panels rise and fall with fluctuating water levels. The retainers vertically track in three semi-closed channels bolted to the chute or bulkhead at 2.5-m intervals. The panels were coupled to the retainers by threading a connector picket through the outside yokes of each terminal panel and the sleeves (made of 3.5-cm [$1^3/_8$ in] inside-diameter schedule 40 aluminum pipe) of three retainers.

Fish passage between each bulkhead and the stream bank was blocked by the rigid weir sections. Two stringers were bolted to each bulkhead and fastened to the stream bank. Aluminum pickets were then inserted through holes in the stringers and sandbags were placed at all possible erosion points.

In addition to passing fish, the Kwethluk weir was designed to pass boats over three modified panels on which wood stringers were replaced with aluminum. The downstream end of each picket was heated and turned downward 45° allowing boats to pass without snagging. Hooks on the upstream stringer were also replaced with turnbuckle jaw ends to keep the panels from becoming jarred loose from the cable. A 5-mm ($^3/_{16}$ in) cable was attached to the center panel and threaded through a pulley anchored to the stream bed. The cable was passed around a sheave mounted to the bulkhead and up to a winch. Upon tightening the cable, the center panel and portions of each adjacent panel submerged allowing boats to be driven or pulled upstream or drift downstream over the weir.

Performance

The Tuluksak River weir was operated from mid-June through mid-September during 1991, 1992, and 1993. The Kwethluk River weir was operated from mid-June through mid-September during 1992. An attempt was made to install the Kwethluk River weir in 1991, but exceptionally high water made it impossible to work in the river. The weir

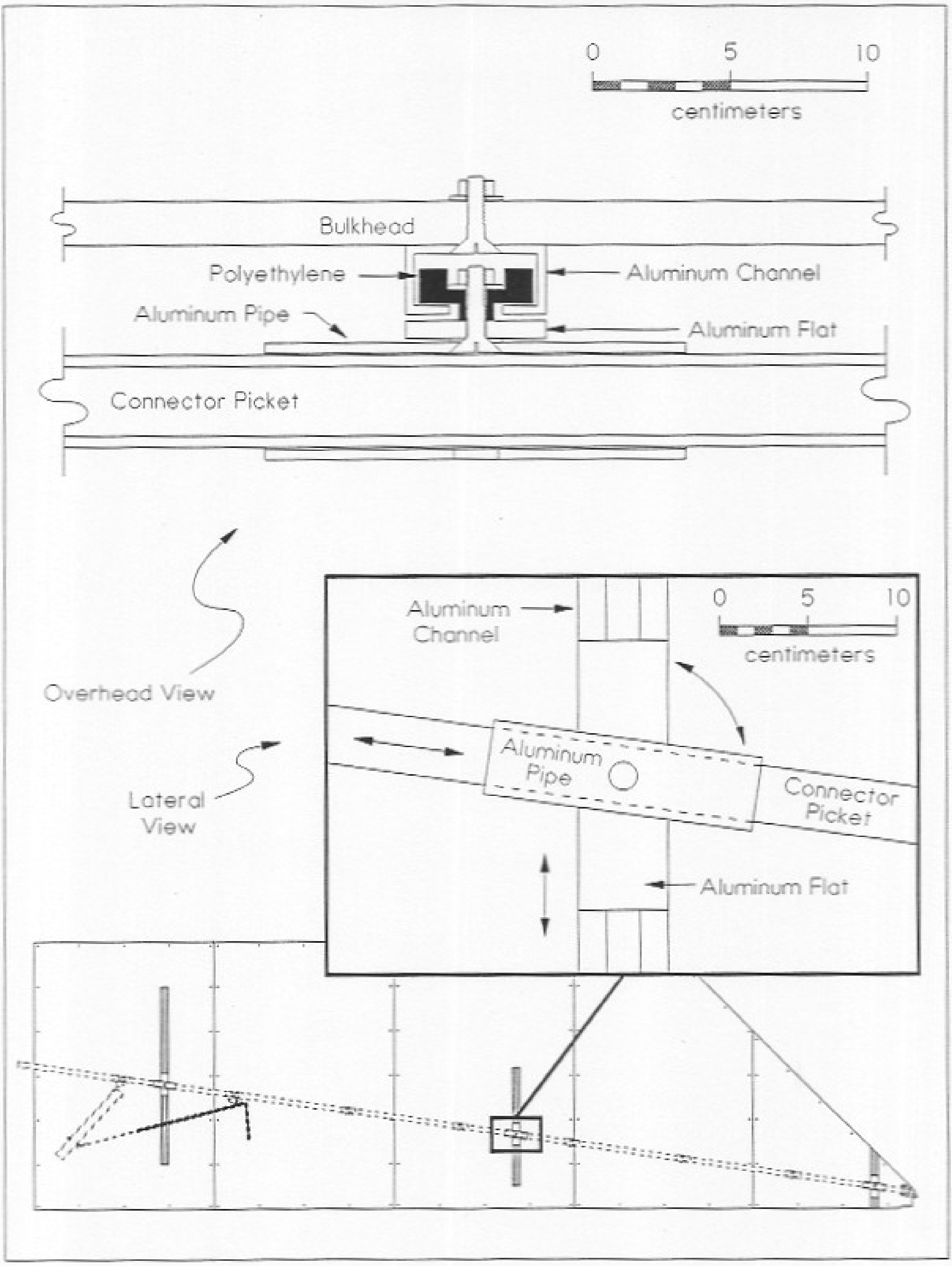

FIGURE 10.—Lateral view and overhead cutaway detail of a panel retainer. Double arrows in lateral view indicate tracking and pivoting action of the retainer and connector picket.

was installed in mid-May, 1992, following break-up and prior to major snowmelt runoff when water depths ranged from 0.1 m to 0.9 m. The weir was not operational until mid-June when the resistance boards were set. The delay was chosen because salmon migration was minimal and damage from trees and ice floes drifting downriver was possible.

Various sized ice floes drifted down the Kwethluk River for a week following installation, and large trees passed over the weir during the heavy runoff period from late May to mid-June. The estimated surface area and thickness of the largest ice floe exceeded 45 m^2 and 0.7 m. The longest tree, including a large root mass, exceeded 12 m.

Both weirs remained operational during a variety of flows. A stream discharge of 81.0 m^3/s was measured using a Marsh-McBirney® (Model 201-D) flow meter and a top setting wading rod (Hamilton and Bergersen 1984) at the Kwethluk weir site on June 11, 1992. This was a moderately high discharge for the operational period of the weir. On this date, a fixed staff gauge mounted downstream of the weir indicated a stage height of 89 cm. The average and maximum water depths across the channel at this level were 0.9 m and 1.5 m. Water velocity averaged 1.4 m/s across the channel and reached 1.7 m/s at the thalweg. Staff gauge levels through the operational period of the Kwethluk weir averaged 71 cm. Maximum and minimum levels were 103 cm and 56 cm. Flows on the Tuluksak river were considerably less than those experienced on the Kwethluk River.

When heavy debris loads accumulated on the panels, the affected section of weir sometimes submerged and allowed the majority of debris to wash off. Occasionally, panels remained submerged until they were cleaned by weir personnel. A 15-m section of the Kwethluk weir sank below the water surface during a high water event registering 103 cm on the staff gauge. The force of the current thwarted attempts at maintenance and cleaning, but the weir remained functional.

During the 8 days that a section of the Kwethluk weir was sunk, 7,204 fish passed through the counting chute and 2 were observed passing over the submerged panels. Observation for escapement over the panels rarely exceeded 2 hours per day; it is therefore likely that more fish passed upstream undetected. Booth (1993) reported that an estimated 10,000 sockeye salmon escaped over submerged panels of a resistance board weir in the Uganik River during 1991.

Large objects, such as trees and frozen sod from eroding river banks, were occasionally stopped by the weir. They were typically rolled downstream over the panels, but some were too heavy for three people to handle. In this situation, the object was either pulled over the weir with a boat or separated into manageable pieces.

A section of stream bed under the Kwethluk River weir washed out during a spring high water event which lasted over two weeks. A barrier, installed upstream of the live trap to deflect ice floes, diverted flow and increased water velocity through a section of weir. The accelerated current scoured a large section of substrate from beneath the rail and one bulkhead. The weir stayed in place despite an estimated 3 m^2 hole under a 10-m span of substrate rail. The hole was filled with chain link fencing and sandbags when the water subsided to a workable level.

To minimize migrational delay (Clay 1961; Ruggles 1975; Backiel and Welcomme 1980), the passing chute was installed where fish could easily locate it and pass upstream. Behavior and numbers of fish downstream of the weir were also monitored for signs of migrational surges. The trap was opened to correspond with migrational activity allowing maximum fish passage.

Escapements exceeding 133,100 and 13,400 adult salmon per season were enumerated in the Kwethluk and Tuluksak rivers, respectively. Species were visually identified as they passed through the counting chute at the upstream end of the trap. When water was turbid, identification was facilitated by partially raising the hinged counting gate on the trap to direct fish towards the water surface as they exited the trap. Except during low discharge periods, fish showed little hesitation in passing over the partially raised gate.

Fish that are sampled for biological information may become stressed during handling (Ruggles 1975). During the first year of weir operation, stressed fish sometimes attempted to return downstream and washed onto the weir panels. To minimize this problem, a recovery sanctuary was provided for handled fish. The sanctuary included a calm water area between the live trap and river bank. The rigid weir section formed the downstream border of the sanctuary. The three-sided enclosure allowed fish to recover from handling and then swim upstream.

Dead spawned-out salmon sometimes accumulated on the weir panels creating weight and resistance. It was often possible to remove carcasses by walking across the weir and allowing fish to wash off as the panels sank; however, the aid of a gravel rake was often necessary.

Live fish also affected weir performance. Spawned-out and injured salmon drifting downstream were eventually stopped by the weir. As they traversed the face of the weir seeking a downstream opening, gravel was disturbed and washed onto the panels. The activity of salmon excavating redds immediately upstream of the weir had the same effect. Occasionally, this caused an accumulation of gravel in the gaps between pickets and required cleaning. Gravel accumulation reduced performance by adding weight to the panels and blocking the gaps between pickets.

Discussion

This design offers an alternative to other portable weirs, because it provides a reliable method of monitoring salmon escapement and collecting biological data over a wide range of conditions. During debris laden high water periods the possibility of washout is reduced because weir panels will self-clean by sinking beneath the water surface. In contrast, other weirs demand careful attention to fish carcass and debris accumulation.

Although self-cleaning decreases the possibility of washout, weir integrity is dependent on foundation design. Washout is typically initiated when unstable bed material is scoured from under the foundation by percolation of flow through pervious substrate. An apron or cut-off wall that increases resistance to flow through bed material will minimize scour beneath the weir (Clay 1961).

The apron in this design functions primarily as a barrier to fish passage beneath the rail and offers marginal protection against stream bed erosion. Gravel retention is aided by the chain link mesh, but scouring flow through pervious substrate beneath the weir is not adequately restricted.

This design was subject to impact from trees, boats, and ice floes. Durability of the polyethylene and metal parts was exceptional. PVC picket strength was adequate with some minor breakage occurring primarily at the boat passage area. Slippage or breakage of the wood stringers and plastic conduit hangers occurred most frequently; thus modification by substitution of more durable materials is recommended.

The passing chute functioned appropriately but was large and difficult to move after it was installed. A smaller chute that is interchangeable with the weir panels would be more versatile. An interchangeable design would also be beneficial if extreme water levels or changing fish movement patterns necessitated adjustment of the chute location. Furthermore, a smaller, interchangeable design would be less expensive, lightweight, and easier to transport.

Downstream movement of fish can be blocked or delayed by a weir. If this is encountered, a panel can be sunk or removed in less than 5 minutes allowing fish to pass through the resulting gap. A downstream trap can also be incorporated into this design if necessary.

Resistance board weirs can be tailored to a variety of stream characteristics and fish sizes by altering panel length, picket spacing, and resistance board size. A post-construction cost estimate of materials, excluding shipping, was approximately $15,000 for one 70-m weir in 1991.

Acknowledgments

Special thanks is extended to the following people: Ken Harper, the biologist in charge of these projects, generated many of the design ideas that made them successful. Biological technician Ted Otis was invaluable during design and construction of the weirs. Biological technicians Brad Benter and Jim Lazar are responsible for much of the quality workmanship that made these projects a success. Co-workers Doug Palmer and Jeff Booth labored many hours in the cold water during installation and removal of the weirs. Thanks is also extended to personnel at the Kenai National Wildlife Refuge and Yukon Delta National Wildlife Refuge for providing work space and equipment vital to the completion of these projects.

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APPENDIX A.—Approximate weights and fabrication time for the major components of a resistance board weir spanning 70 meters. Fabrication time does not include design, purchasing, shipping and handling.

Component description	Weight	Quantity required	Approximate fabrication time (man hours)	
			Service	Contractor
Weir panels	68 kg each	47 each	280	10
Boat passage panels	70 kg each	3 each	20	1
Substrate rail	40 kg per 3 m	69 m	1	23
Bulkheads	175 kg each	2 each	30	1
Bulkhead adapter	10 kg each	1 each	0	1
Winch stanchion	32 kg each	1 each	1	4
Passing chute	250 kg each	1 each	20	7
Live trap	260 kg each	1 each	40	2
Apron	45 kg per 15 m	64 m	5	0
Rigid weir	65 kg per 3 m	6 m	3	0
Substrate pins	1.7 kg each	170 each	0	11